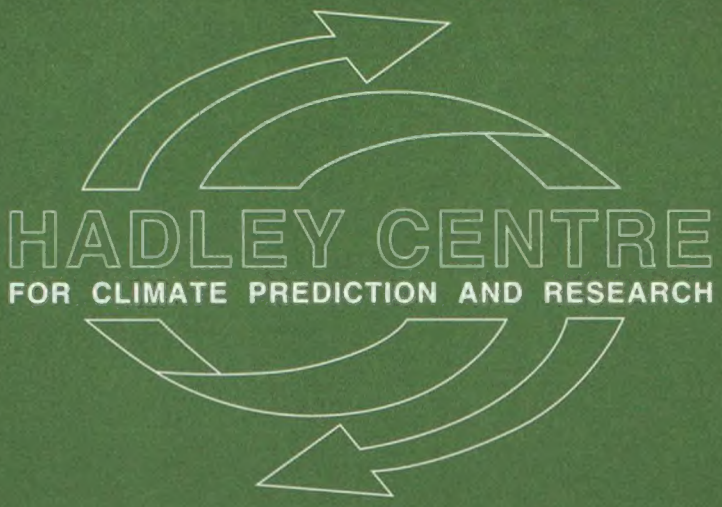

Seasonal Forecasting

by

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CLIMATE
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NOTE

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Seasonal forecasting

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SUMMARY

Examples are used to provide an appreciation of the most recent developments in real-time experimental and operational seasonal forecasting and also of some of the wider issues surrounding the provision and use of such forecasts. The stimulus provided by the study of the El Niño - Southern Oscillation phenomenon is discussed, especially with respect to operational seasonal forecasting in the US National Weather Service. The Met. Office's seasonal forecasting activities and objectives are then reviewed briefly, leading to a description of, and some tentative results from, a major European collaborative project on Prediction Of Climate Variations On Seasonal to Interannual Timescales. A wider international perspective is given by considering the relevant projects of the World Climate Programme and also the proposal for an International Research Institute for Seasonal-to-interannual Climate Prediction. In conclusion, some further general issues are raised for consideration.

KEYWORDS: Seasonal forecasting Climate prediction
El Niño - Southern Oscillation International climate programmes

1. INTRODUCTION

The last ten years or so have witnessed a major expansion of research into, and consequently, understanding of, the predictability of the atmosphere at seasonal-to-interannual timescales. Exciting and useful results have already been achieved, with the prospect of further valuable applications to follow by the turn of the century and beyond. It seemed timely therefore to choose Seasonal Forecasting as the subject for a Presidential Address.

There are several excellent recent reviews of the scientific and technical progress that has paved the way for real-time experimental and operational seasonal forecasts (see, for example, Palmer and Anderson (1994), Barnston *et al.* (1994), Davey (1996), NRC (1996)). It is the latter practical aspect, rather than the former scientific aspect of the subject that I want to focus on; hence the use of 'Forecasting', as opposed to 'Predictability', in the title.

My presentation of some of the current and planned activities in seasonal forecasting is necessarily selective and therefore subjective. My main aim, nevertheless, is to use such examples to provide a critical appreciation not only of the most recent forecasting results but also of some of the wider issues surrounding the provision and use of seasonal forecasts. Whilst not ignoring statistical techniques, any slant in the

presentation will be towards the newly-emerging results from the development and application of dynamical predictive models.

First, I shall consider briefly the stimulus provided by the recognition and study of the El Niño - Southern Oscillation (ENSO) phenomenon, especially through the Tropical Ocean and Global Atmosphere (TOGA) project of the World Climate Research Programme (section 2). Then I shall describe some of the seasonal forecasting activities at The Met. Office (section 3), which will lead naturally to PROVOST, a European collaborative project (section 4). I shall then discuss briefly some evolving international activities (section 5) before concluding with further personal reflections on some of the general issues raised for consideration.

I wish to acknowledge at the outset the generous and valuable help I have received from several colleagues, especially at The Met. Office, who have provided the advice and results that my examples are drawn from (see Acknowledgments).

2. THE ENSO STIMULUS

(a) Basic premise

The principal scientific basis of seasonal forecasting is founded on the premise (see, for example, Palmer and Anderson (1994)) that lower-boundary forcing, which evolves on a slower timescale than that of the weather systems themselves, can give rise to significant predictability of atmospheric developments. These boundary conditions include sea-surface temperature (SST), sea-ice cover and temperature, land-surface temperature and albedo, soil moisture and snow cover, although they are not all believed to be of generally equal importance. In this context, it is interesting to note that, in his 1985 Presidential Address, Gilchrist (1986) spoke of the introduction of SST anomalies into the practice of monthly forecasting (by, in particular, Ratcliffe and Murray (1970)) as breaking new ground, and that generally during the 1970s the influence of other surface anomalies was being given increasing weight in making such forecasts.

The strongest evidence for long-term predictability comes largely from the influence of persistent SST anomalies on the atmospheric circulation which, in turn, induces seasonal climate anomalies. The most well-known of these are related to the El Niño and the Southern Oscillation (collectively called ENSO) coupled ocean-atmosphere phenomenon in the tropical Pacific Ocean (see, for example, Allan *et al.* (1996) and Barnston (1995)).

(b) TOGA

A key factor in recent progress has been the success of the Tropical Ocean and Global Atmosphere (TOGA) project of the World Climate Research Programme (WCRP). Its ultimate backing, especially by the USA, was motivated and eventually secured by the mounting evidence of its potential importance from a number of scientific, technical and practical sources, including:

a. increasing recognition of the scientific importance of natural variability in the climate system;

b. the existence of scientific hypotheses about the influence of SST anomalies on the atmospheric circulation (see, for example, Bjerknes (1966, 1969)) which needed to be tested, and could be;

c. recognition of the potential consequences of the ENSO cycle (in particular the significant El Niño of 1982-83) not only for its influence on the world's weather but also for its worldwide socio-economic impacts (especially in the USA);

d. increasing realisation of the potential value of skilful predictions.

The TOGA Programme (1 January 1985 - 31 December 1994) was designed to study seasonal-to-interannual variability and predictability around the globe, with an emphasis on ENSO. In the event, available resources limited the programme largely to studies of ENSO in the tropical Pacific region. In spite of this, TOGA is widely recognised as being the first major success of the WCRP and the substantial progress it achieved is reflected in what can be done, and what is being done, today. In particular, TOGA has provided :

a. improved physical understanding of the climate system. A new depth of understanding of ENSO has been achieved; theoretical models for the mechanism of ENSO have been proposed, and the relationship between tropical SST perturbations and the atmospheric response in the middle latitudes is beginning to be unravelled;

b. an improved ability to measure the upper ocean, using both enhanced *in situ* observations, and remotely-sensed measurements. Again, particularly for ENSO in the previously poorly-sampled tropical Pacific, a new capability for observing the surface and near-surface ocean and atmosphere in real time has been developed;

c. the development of increasingly realistic coupled ocean-atmosphere models particularly of the tropical Pacific Ocean, some of which now demonstrate skill in predicting tropical SSTs months to a year or so in advance; in particular, the predictability of El Niño (at least on some occasions) has been demonstrated;

d. the availability of long (in many cases multi-decadal) datasets with stringent quality control; in particular for global SSTs;

e. more-advanced techniques, not only for providing observations, but also for their analysis and assimilation into atmospheric and ocean models.

Although not directly related to TOGA, another key enabling factor in today's activities is undoubtedly the widespread availability of increasingly powerful computing facilities.

A comprehensive review of the accomplishments and legacy of TOGA has been published by the National Research Council of the USA (NRC, 1996). It is also

appropriate to draw particular attention to a series of related articles in the special edition of *Weather* (December 1995), dedicated to the memory of Robert Ratcliffe, one of the recognised pioneers of the application of SST anomalies in long-range weather forecasting.

(c) Experimental Long-lead Forecast Bulletin

A good indication of how much progress has been made in recent years, particularly in ENSO-based techniques, can be gained from the *Experimental Long-lead Forecast Bulletin*, issued quarterly by the Climate Prediction Center (CPC) of the National Centers for Environmental Prediction (NCEP), US National Weather Service, National Oceanic and Atmospheric Administration (NOAA). This is intended to present experimental long-lead forecasts (*i.e.* forecasts made at least two weeks before the beginning of the forecast period) of short-term climate fluctuations in real time. Accompanying each forecast is a brief discussion of the forecast method and its estimated skill. The intention is to achieve an exchange of ideas on long-lead forecasting in order to stimulate research in this area. The *Bulletin* is intended mainly for forecasts of the surface climate in the USA, but forecasts of other features and events, such as ENSO, hurricane-season severity, and surface climate in other parts of the world are also welcome.

To achieve its aims with credibility and scientific integrity, the *Bulletin* requires contributions to meet laid down guidelines and standards, including four criteria for acceptability, *viz.*:

a. Reproducibility: the forecasting method used must be describable in terms such that others could generate an identical forecast by following its description - at least in principle.

b. Skill: a track record is required. A clear demonstration of the skill of the method must be available, and this should be better, beyond reasonable doubt, than that of random forecasts.

c. Documentation: a description of the method must be available in at least a non-refereed publication.

d. Presentation standards: the forecast should be cast in unambiguous terms. It should be quite clear, what is being forecast, what the forecast is and how it can be verified.

The widespread adoption of such criteria is, I believe, particularly important at this relatively early stage of the development, provision and use of long-lead, seasonal-to-interannual forecasts which, generally speaking, have low levels of skill. The strict adherence to such criteria offers the prospect of a 'Charter' for providing some assurance to potential users about the integrity of these difficult forecasts and the spirit and good faith in which they are made available, particularly at the experimental phase.

(d) Operational seasonal forecasting in the US National Weather Service

Arguably, the most ambitious and comprehensive move by an official Public body to make the transition from experimental long-lead forecasting to official, operational long-lead forecasting has been taken by the National Weather Service of the USA (US NWS). Its implementation of this step is such that the main operational techniques employed by the CPC of the US NWS are no longer presented in detail in the *Experimental Long-lead Forecast Bulletin*. However, a brief summary of the official operational output is published there. By way of example of what has been achieved to date, mainly on the basis of ENSO-related influences, I want to dwell briefly on the operational techniques now used in the US NWS.

Operational multi-season climate forecasting is done at the NCEP and the forecasts routinely disseminated by the CPC. The forecasts are based on three methods, two of which are statistical, the other dynamical (see, for example, van den Dool (1996)):

a. Canonical Correlation Analysis (Barnston 1994)
b. Optimal Climate Normals (Huang *et al.* 1996)
c. Coupled Model Forecasts (Ji *et al.* 1994a,b).

Every month a suite of 13 seasonal forecasts is issued, going forward in time in overlapping fashion with steps of one month out to the next year. For example, in mid-January 1997, forecasts were issued for the following 13, 3-monthly periods : FMA(97), MAM(97), AMJ(97), ------, FMA(98). Thus the forecast for FMA(97) would have been updated every month from mid-January 1996 until mid-January 1997, when the final FMA(97) forecast was issued.

One basis for issuing such forecasts out to a year is that, in CPC's experience, the skill of its seasonal forecasts is much more a function of the season being forecast for than of the lead-time of the forecast. They experience two maxima in skill, one at the end of winter (JFM), the other at the end of summer (JAS), with two minima in between. This 'two peak - two valley structure' in the achieved skill is found regardless of the length of the lead-time. Van den Dool (1996) states, 'for the times in the year of maximum skill one can state that whatever little we know, we know it well in advance, *i.e.* the skills at leads of 1 and 4 months are quite close, and skill remains non-zero out to at least a year'. However, the forecasts for some periods during the transition seasons (late autumn in particular) have relatively little skill, even at the shortest leads.

I want to concentrate here on only the last method (*i.e.* Coupled Model Forecasts (Ji *et al.* 1994a,b)) as an example of the furthest the coupled modelling technique has yet been adopted into operational seasonal forecasting. In particular, it focuses at present on the seasonal timescales and its skill is predicated on ENSO-related impacts over the USA.

The forecasts are performed in a two-tiered fashion. The first tier comprises an integrated ocean model - data assimilation system which assimilates a range of surface and sub-surface ocean data from the tropical Pacific (ENSO area) into an

ocean model. This ocean data assimilation system (Ji *et al.* 1995) provides the ocean thermal fields, including SST and sub-surface temperatures, to initialise the ocean component of a coupled ocean-atmosphere general circulation model. To date, only the tropical Pacific is coupled interactively to the atmosphere in this coupled model which, in turn, is used once a week to generate forecasts of tropical Pacific SST anomalies out to a year ahead. These SST anomalies are a product in their own right. As expected, the skill in predicting such SST anomalies is highest for a single-season lead and deteriorates with increasing lead-time. However, significant and useful skill has already been demonstrated out to several seasons ahead. The performance of NCEP's coupled model predictions of ENSO is discussed fully in Ji *et al.* (1996).

The forecast SST anomalies are then used as input to the second tier of the system which, once a month, uses a climate version (T40L18) of NCEP's global atmospheric forecast model to generate ensembles of global forecasts out to three seasons ahead. At time of writing, there are 25 members in each ensemble forecast. This provides NCEP with the capability of making forecasts of seasonal surface temperature and rainfall anomalies over the USA, where the skill is conditioned on there being significant SST anomalies in the tropical Pacific. Again, in this context, significant and useful skill has been clearly demonstrated, linked in particular to the phases and strengths of the ENSO signal in the tropical Pacific. However, because of the inherently moderate predictive skill, and because the ensemble technique allows a probability forecast, it is thought more sensible and more useful to provide a probabilistic rather than deterministic forecast. There is still a lot to be done in understanding how such probabilistic information can be used, and how best to present the information to informed customers.

Such products from the NCEP are passed to the CPC which has the responsibility and the authority for issuing the official NWS operational seasonal forecasts for the USA. The dynamical-model output from NCEP is combined with the two other, statistical techniques (Canonical Correlation Analysis and Optimal Climate Normals), to produce the full, official operational products. Note that all the above methods are, in principle, applicable anywhere over the globe. So while used operationally at present only for US seasonal forecasts, these methods are also relevant elsewhere, depending on any skill which can be derived from their experimental testing.

Note also that all the US NWS operational seasonal forecasts are freely available on Internet. The forecasts themselves are contained in the official *Climate Outlook*, available freely on Internet with address : http://nic.fb4.noaa.gov. The same address can also be used to access the web site for the *Bulletin*: http://nic.fb4.noaa.gov/products/predictions.

3. SEASONAL FORECASTING AT THE MET. OFFICE

(a) Tropical seasonal rainfall forecasts

SST anomalies, which tend to persist for several months or longer, can have a strong influence on seasonal atmospheric anomalies, especially in the tropics. Motivated by

this realisation, experimental techniques using global-scale patterns of historical SST anomalies have been used successfully since 1986 at The Met. Office to make real-time experimental forecasts of seasonal rainfall in NE Brazil and tropical NW Africa (see, for example, Ward and Folland (1991), Folland *et al.* (1991), Ward *et al.* (1993) and Rowell *et al.* (1995)), and more recently in East Africa. Using statistical methods, the relation between regional atmospheric anomalies and pre-season SST anomaly patterns can be studied using historical data for many years. Where significant links are found, current SST patterns can be used to predict future atmospheric anomalies. Note that such predictions are not deterministic: statistical forecast methods provide an estimate, based on past experience, of the atmospheric seasonal anomaly that is likely to occur. Such statistical methods have now been applied for many regions of the world and examples of experimental predictions for regions in tropical and sub-tropical Africa, North and South America, and the Pacific sector, can be found in the NOAA *Experimental Long-lead Forecast Bulletin.*

Correlations between SST anomalies and local rainfall series form the basis of a number of statistical methods used in the prediction schemes. These forecasts use SST anomalies for 1-3 months before the main rainfall season to predict the rainfall total for that season. Note that, for NE Brazil, ENSO plays a significant but not the dominant role in the statistical prediction scheme. Indeed, the NE Brazil forecasts use SST 'modes' in the tropical Atlantic and the whole Pacific. In contrast, the tropical N African forecasts combine worldwide 'modes', with particular focus on tropical Pacific and Atlantic anomalies and inter-hemispheric differences.

To date The Met. Office's seasonal rainfall forecasts have been based mainly on such statistical methods, but dynamical methods, using various combinations of coupling atmospheric and ocean circulation models are also being developed and are now also being applied and assessed routinely. Figure 1 indicates the regions of the globe for which routine experimental seasonal forecasts are currently made in The Met. Office. In particular, the current list of quasi-operational forecasts of seasonal rainfall that the Met Office makes and issues for selected tropical regions is :

a. North-East Brazil : March - May rainfall season. A preliminary forecast is issued in early February and an updated forecast at the beginning of the season (early March). Real-time experimental forecasts of seasonal rainfall in the North Nordeste region of Brazil have been made since 1987 using statistical techniques with January SST anomaly patterns as predictors. In addition, dynamical forecasts have been made since 1994, using an atmospheric general circulation model (AGCM). Results from the AGCM with observed SST suggest high predictive skill, similar to that of the statistical models, for rainfall in NE Brazil.

b. Tropical North Africa : July - September rainfall season. Forecasts are issued in early May (preliminary) and early July (update). Real-time experimental forecasts of seasonal rainfall in the Sahel region, as defined by Nicholson (1985), have been made since 1986. These were extended in 1992 to: the gridded Sahel region; the (gridded) Soudan region; and, the (gridded) Guinea Coast region (all shown in Fig. 1). The statistical forecasting techniques are based on March and April SST anomaly patterns. Dynamical seasonal forecast information from an AGCM has also been used for the predictions since 1994.

c. Tropical East Africa : October - December 'short rains' season. A forecast is issued in early October. Real-time experimental forecasts for this region were introduced only in 1994. The region covered by the East Africa prediction is between 5°N and 15°S and between 30°E and the Indian Ocean coast (see Fig. 1). The statistical forecast is made by using linear regression and discriminant analysis techniques, with three indices of global SST patterns and an index of local Indian Ocean SST as predictors. The forecast is derived from historical rainfall and SST information.

Note that, at this stage, the above tropical rainfall forecasts are very selective, being for the peak rainy seasons only in specific regions; such seasonal forecasts are not being made and issued for each month of the year or for all parts of the globe. Also, the results achieved from the statistical methods are very encouraging and remain a target to be met by the dynamical methods. It is likely that the best forecasts will be produced by an objective combination of both methods - at least for the foreseeable future.

Our aim is that the disseminated forecasts should: be self-contained; be understandable to the intelligent user; and, contain some additional technical information and detail that has added value for those recipients who have a good level of meteorological expertise. The research and experimental character of the forecasts that are being issued is made clear, as are the areas being forecast for and the SST anomaly patterns that have been used as the basis for the statistical techniques. A qualitative description is given of what the relevant recent SSTs have been and what our increasing empirical knowledge tells us about the likely consequences for the seasonal rains in the regions being forecast for. Two statistical techniques are typically used: linear discriminant analysis and multiple linear regression. One forecast is given in terms of a probability of the forthcoming season being in each of five categories (very dry, dry, average, wet, very wet) which have been evaluated from past data as being equiprobable over a specified period. So to interpret this alone, the recipient has to know the details of that particular climatology. To help the recipient convert these categories into meaningful rainfall amounts, they are also expressed in terms of additional climatologies; ones which are fairly universally used and readily available for the region and also ones for a relatively recent period, so that the categories and forecasts can be interpreted in terms of recent experience. One forecast can then be expressed in percentages of these available and recent climatologies. Additional information is given of the dynamical techniques now being used and it is stressed that their predictive skill has not yet been fully assessed for the regions under consideration. This again emphasises the experimental nature of the forecasts.

Finally there is a forecast summary, where we provide our best estimate of the forecast for each region, taking into account, in a partly subjective way, the output from each of the techniques employed. Again, there is an attempt to put the forecasts in the context of the more commonly used and available climatologies - and recent experience. Note also that an indication of our confidence (always conservative) in the forecasts is given as well as a final cautionary reminder that the forecasts are experimental and should be used with caution.

(b) Verification of forecasts

An important aspect of seasonal forecasting for both the researcher and the recipient of the experimental forecasts is a measure of the skill they have achieved. This is necessary to enable the recipients to form a realistic level of confidence in the forecasts based on their performance and the experimental nature of the techniques being used. It is an important step in establishing that due caution is needed in the interpretation and use of such forecasts. Graphs of the history of the performance of The Met. Office's tropical seasonal rainfall forecasts are updated and disseminated with each forecast made.

Figure 2 illustrates the verification for the NE Brazil forecasts made since 1987. This region has high predictability and the statistical forecasts issued since 1987 have a consistently high level of skill. For most of the period three different measures of NE Brazil rainfall have been used to assess the skill of the forecasts: a series based on a number of stations chosen by Hastenrath *et al.* (1984); data from a larger area of the North Nordeste, deemed the 'Nobre' series; and, data from only two stations, Fortaleza and Quixeramobim (see Ward and Folland (1991) for details). For comparison, Fig. 3 illustrates the corresponding verification graphs for the seasonal rainfall forecasts for N Africa. Note that, although the general levels of skill achieved are encouraging, they are more variable than that achieved for NE Brazil.

The NE Brazil real-time forecasts are currently performing better than those for the Sahel (and other parts of N Africa). However, based on many test forecasts made for past years using historical data, the average skill of the forecasts for both regions is expected to be similar (to the mean of the current Sahel and Brazil values). On performance to date, one would place more confidence in our forecasts for NE Brazil than in those for N Africa. This needs to be impressed on the recipients of these forecasts.

(c) Dissemination of seasonal forecasts

The dissemination of seasonal forecasts is a sensitive and difficult issue which is currently being addressed by the national and international agencies engaged in such activities. The issues involved go beyond the science and the technology to also include political and socio-economic concerns. I shall return to such general issues later (under sections 5 and 6), but for the moment I shall comment only on the procedures adopted in The Met. Office for disseminating our seasonal rainfall forecasts for NE Brazil and parts of Africa. This will illustrate and draw attention to some of the important and difficult issues that arise when considering how best to disseminate such information.

The forecasts are first sent to the National Meteorological Services (NMSs) and closely-related agencies of the regions involved. In this way our forecasting efforts attempt to enhance rather than undermine the position and credibility of those NMSs. Then after a delay of 2-4 weeks they are sent to specific international agencies, other

institutes and collaborating scientists. They are placed fully in the public domain at a later date through, for example, publication in the NOAA *Experimental Long-lead Forecast Bulletin* and placement on The Met. Office internet site.

Forecasts are delivered using the method chosen by the recipient, and delays due to lack of computer technology or facsimile machines often reduce their timeliness and potential value. An important but relatively undeveloped aspect of the whole procedure of issuing experimental seasonal forecasts is getting critical feedback from the agencies we send them to. Useful information from such 'users' would include: how are the forecasts interpreted and used; what value is placed in them; are they used to provide customer-specific products for third parties; what typical applications are they used for; what value do the end-users place in such information; and, is any use in fact made of the forecasts?

We have solicited such feedback from those who receive our forecasts, but with limited success only. To date, all of the forecast recipients are keen to continue to receive them. One NMS combines the forecasts with other local information to inform its Ministry of Agriculture. However, since the forecasts are experimental, rather than 'operational', they are not used directly for strategic planing. Another NMS reported using the forecasts to plan seasonal crop planting. One user (not an NMS) is looking forward to the stage where such forecasting information can be integrated into its crop models. Rainfall predictions are also being used in the context of planning for power generation.

There is clearly a need for more interaction with customers. In this general context, Nicholls (1996) has produced a valuable review of the economic and social benefits of climatological information and services. There is a particular need to learn how to use the inherently modest amounts of probabilistic skill that, in general, will limit the value of seasonal and longer forecasts for mid-latitudes.

(d) Central England Temperature

The problem of making reliable seasonal predictions for aspects of the UK's climate is more difficult than that of predicting seasonal rainfall amounts in the tropical regions discussed above. Nevertheless, there is some evidence of potential predictability from SST (see, for example, Ratcliffe and Murray (1970) and Palmer and Sun (1985)).

Bearing in mind the achievements of the TOGA Programme (see section 2), the possibility of using such statistical relations has recently been investigated further and Colman (1997) has demonstrated a statistical link between wintertime SST anomalies in the North Atlantic and Central England Temperature (CET) the following summer. This connection is now being used to make experimental statistical forecasts for the mean July-August CET based on a linear regression method; for details of which see Colman (1997). (Note that the CET is a homogenised temperature series from 1659 to the present, first put together by Manley (1974) and updated by Parker *et al.* (1992). From 1877 on, CET is based on the average of daily maximum and

minimum temperatures as observed at a number of selected meteorological stations in the region.)

Figure 4 shows the degree of correlation between the observed CET and the forecasts obtained from Colman's linear-regression method, over the period 1946-95. The correlation between the two series is about 0.5 and judged to be significant enough to be used to make experimental real-time, long-lead forecasts of CET. Note that the statistical link is weak, and the forecasts accordingly have a wide uncertainty that makes specific application difficult. This inherent uncertainty in the method is acknowledged in Fig. 5, which presents a probabilistic, rather than a deterministic, type of forecast to the user. It shows again the forecasts plotted against observed CET; but in this case the forecasts are depicted as a temperature range, with the range chosen such that, in the period 1956-96 shown, half the observations fall within the indicated range. For comparison, in a simple 'climatological' forecasting method, the predicted range for each year is centred on some average temperature. For the years 1956-96, 50% of the July-August CET values were within the 'average' range 15.1-16.8 °C, with 25% above that range and 25% below.

This SST connection was used for the first time in 1996 to make an experimental, real-time statistical forecast for the CET in July-August 1996. The forecast for 1996 was 15.4 °C with a standard error (evaluated over the period 1971-1995) of 1.2 °C which provides another indication of the reliability of such forecasts; *i.e.* from these results, the error between predicted and observed CET is expected to be larger than 1.2 °C for about 1 out of 3 forecasts. The observed value was 16.5 °C. The 1.1 °C difference between forecast and observed was therefore slightly less than one standard error and therefore consistent with the expected error based on historical data.

A further experimental, real-time forecast was made in early March 1997 for the mean CET in July-August 1997 using Colman's linear-regression scheme. The forecast gives a 50% probability that the 1997 July-August CET will be within the range 14.4 - 16.1 °C (see final vertical bar in Fig. 5). By contrast, a 'climatological' prediction suggests a 50% probability that CET will be within the range 15.1 - 16.8 °C. Although Colman's method gives values slightly lower than the 'climatological' method, the difference is small compared with expected variations. This information is available via the Met Office internet site at http://www.meto.gov.uk/.

So far, no similar levels of statistical skill have been found for predicting England and Wales rainfall (Colman, 1997).

(e) European summer temperatures

Consistent seasonal climate anomalies tend to occur over regions larger than Central England and so the above technique for CET has been extended by Davey and Coleman (private communication) to estimate predictive skill for July-August land-surface temperatures over Europe. A dataset based on observations for 1951-96, averaged onto a 2.5° latitude by 3.75° longitude grid, was used for this purpose. Figure 6 shows the correlation between those observations and linear regression

predictions. (Values are centred on the relevant grid area, and thus are displaced from the land in some locations.) There are values greater than 0.5, indicating modest predictive skill comparable with that found for CET, over a wide area covering eastern England, Scotland, France and Germany. Positive values indicate that predicted temperature anomalies for that area have the same sign as CET anomalies: thus warm (cool) conditions can be expected over western Europe when English conditions are warm (cool). Experimental linear-regression seasonal forecasts for July-August are therefore being made and assessed for each gridded area with correlation skill over 0.35, as always with the caveat that such forecasts have substantial uncertainties in accordance with the weak nature of the statistical link between the SSTs and the land temperatures.

(f) Met. Office objectives

From the above it should be clear that The Met. Office has established some useful results from the development and application of empirical seasonal forecasting methods, in particular for selected tropical regions. However, its current and future commitment to research and development in this field will focus mainly on extratropical seasonal-to-interannual predictability and prediction, and the prospects for an operational capability based on the use of global dynamical models.

Put concisely, if somewhat simplistically, the main objectives of our research and development into seasonal predictability and forecasting are : to establish a sound scientific basis for seasonal prediction; to determine for which regions of the globe an operational system is viable; and, in particular, to determine how feasible it is to achieve skilful seasonal predictions for Europe. To this end, one particular current activity on mid-latitude seasonal predictability aims to assess the predictability of the atmosphere on the seasonal time-scale with particular focus on Europe. This is being tackled through a series of experiments for each season of the year using The Met. Office's Unified Model. Part of the strategy in all of this effort is that, wherever possible, significant gearing will be sought through external collaboration. This is exemplified by our active involvement in the PROVOST project discussed below.

4. PROVOST : A EUROPEAN COLLABORATIVE PROJECT

(a) Objectives

PROVOST is a major collaborative European project on **PR**rediction **O**f Climate **V**ariations **O**n **S**easonal to Interannual **T**imescales, involving 11 institutes (comprising National Meteorological Services, university departments, industrial and other research laboratories) in six countries (Denmark, France, Germany, Italy, Spain and UK). It is a three-year programme, co-sponsored by the European Commission, which began in March 1996 and is co-ordinated by Dr T N Palmer at the European Centre for Medium-range Weather Forecasts (ECMWF)).

The seeds for PROVOST were sown at a workshop held at ECMWF in December 1992, from which Palmer and Anderson (1993) distilled and articulated a European perspective on the scientific assessment of the prospects for seasonal forecasting. This effectively established the scientific basis and rationale that persuaded the Council of ECMWF to approve a three-year experimental programme on seasonal forecasting, which led in turn to the PROVOST project. A version of the ECMWF Report was published as the major review paper by Palmer and Anderson (1994).

Results reviewed in Palmer and Anderson (1993, 1994) suggest that, although the overall level of skill will be smaller in the extratropics than in the tropics, nevertheless, when viewed as a probability forecast, there may be numerous occasions where there is predictive skill for Europe and other extratropical regions. This is the basic rationale for PROVOST, which has the following three principal objectives:

a. to quantify the potential predictability of seasonal mean atmospheric variability, over Europe and other key areas worldwide (where, for example, there may be European interests), based on ensembles of atmospheric model integrations with prescribed observed SST;

b. to develop a suite of fully-coupled ocean-atmosphere models and an ocean-atmosphere data assimilation system to the stage where real-time, operational seasonal forecasting is possible;

c. to test the skill of the coupled systems (developed under b above) through co-ordinated 'hindcast' experiments using cases from the 1980s and 1990s.

Note that the combination of forecasts made with different models and different analysis systems into one probabilistic 'multi-model' ensemble solution is an integral part of this project. To that end, the initial phase of PROVOST, has been devoted mainly to the first objective outlined above, with four groups (ECMWF, UK Meteorological Office (UKMO), Météo-France, and Electricité de France (EDF)) performing the co-ordinated model integrations and their analysis. I shall focus only on some of the tentative results to date from this first component of PROVOST.

(b) Experimental details

The impact of lower boundary forcing, particularly SST anomalies, on atmospheric variability is dependent on position, season and strength of the boundary anomalies. The purpose of the first component of PROVOST is to quantify this dependence more explicitly. In order to do this, ensemble integrations with four different atmospheric models have been run over seasonal timescales with prescribed, observed SSTs. The four different modelling groups (and models) are: ECMWF (IFS T63L31); Météo-France (ARPEGE T42L31); Electricité de France (ARPEGE T63L31); and, UKMO (Unified Model, climate resolution, 2.5° x 3.75° L19, version 3.4).

Each ensemble is 120 days long and consists of 9 members, started from consecutive 12UTC analyses from the 9 days immediately prior to the start of the season. The integrations have been made over the 15-year period (1979-93) of the ECMWF Re-

analysis Project using initial conditions, including SST, taken from the re-analysis. The ECMWF re-analysis fields are also used to verify the ensemble integrations. For each year, ensembles have been made for the four seasons (spring (MAMJ), summer (JJAS), autumn (SOND), winter (DJFM)), except at EDF where only the winter ensembles have been produced. The model 'climates' for each season are formed from all 135 (9x15) ensemble members.

All the PROVOST experiments with uncoupled models have been completed for all the seasons and analyses are under way. The output from all the models is being archived at ECMWF, and multi-model ensemble results will be produced from the full experimental dataset. In the absence of any overall summary of the results to date, I shall indicate some tentative, early results from analyses conducted so far at The Met. Office by Dr M S J Harrison and his co-workers (A D L Evans, R Evans, T P Legg, K B Robertson, M K Davey, A W Coleman and S Ineson; private communication).

(c) Tentative results from The Met. Office Unified Model

Figure 7 is an example of the potential predictability in the extratropics from the UKMO Unified Model. It shows the anomaly correlation coefficients (ACC) between the ensemble-mean predicted 850 hPa temperature fields (T850) for Europe (35-75 °N, 12.5 °W - 42.5 °E) and the corresponding, verifying ECMWF re-analysis fields for each of the 90-day main seasons throughout the period 1979-93. Other fields have been processed in the same way; however, T850 can be thought of as a surrogate for the surface temperature and it is chosen here simply to illustrate the potential of a useful practical quantity.

Skill, as measured by anomaly correlations, varies with the particular field chosen and the domain and season it is being forecast for. Over Europe, the highest levels of skill appear to be in spring, followed by autumn (at least in the UKMO model), then winter. Monte Carlo tests indicate that statistically significant levels of skill are present for at least some fields in all seasons; the UKMO Unified Model achieved such predictability in selected fields in most seasons. For a more detailed examination of seasonal predictability for the North Atlantic and European regions, using an ensemble of multi-decadal integrations with an AGCM, see Davies *et al.* (1997), and for a global extension see Rowell (1997).

All four models perform reasonably similarly, with the UKMO model, not unexpectedly, being more different from the other three than those differ from each other. Figure 7 illustrates that there is clearly skill in some seasons, but not all the time. No model was able to achieve consistent predictability either over the full hemisphere, over Europe or over N America, but the most skilful seasons were generally skilful across all models. This begs the question, can we predict when the models are likely to be skilful?

Attempts to predict skill over Europe have not proved successful to date, but work is continuing in this area. It appears (at least in the UKMO model) that an ENSO event may be a necessary but not a sufficient requirement for European skill in winter when

judged, for example, using 500 hPa geopotential height fields, but that the link between skill and ENSO is not as clear using T850. Also, no immediately apparent link between skill and ENSO exists for the spring season. Other diagnostics, including some that examine skill in a probabilistic sense, also indicate that skill exists across Europe, but that, while on average low, some seasons in some years might be predicted with high levels of skill given a method of identifying such seasons *a priori*.

Figure 8 is an example of early attempts to determine whether or not we can predict when the forecast will be skilful. It is testing the well-known hypothesis that ensembles with low spread may have higher predictive skill than those with high spread. It shows the correspondence between the anomaly correlation coefficients of the predicted ensemble means for the 500 hPa geopotential height fields over the Northern Hemisphere (20-80 ^{o}N) in the winter months (December-February) and a measure of the spread within each ensemble. The spread correlation shown has been calculated by correlating each member of the ensemble with the mean value and then taking the average of those correlations. Therefore, a high value of this index means a low spread within the ensemble. The correlation of 0.71 between the two series in Fig. 8 is significantly high and lends some credence and hope to the view that we may indeed be able to predict some occasions when useful predictability can be expected. However, it appears that the strong spread-skill links discovered so far are not particularly for the seasons with highest basic skill!

Another important practical issue relates to the options available for making operational seasonal forecasts with an atmospheric model. The focus of the first objective of PROVOST is to determine the potential predictability when observed SST anomalies are used. In this context, therefore, it is important to examine the loss of potential when, for example, persisted, rather than observed, anomalies are used as the boundary forcing. Figure 9 illustrates a first attempt to answer such a question. Although rather complicated in its detail, it essentially depicts the correspondence between the skills (anomaly correlation coefficients) of two sets of ensemble predictions for the 500 hPa geopotential height fields over Europe in winter: one of which has been forced by the observed SST anomalies; the other by persisted SST anomalies. By and large, in this particular case of a single-season (winter) forecast, the persisted-SST forecasts have compared favourably with the observed-SST forecasts. This is an important practical result. Generally speaking, the case for using the more-expensive coupled atmosphere-ocean models is clearer for forecasts beyond a single season.

A further step, is to explore ways to convert any apparent skill in the models to make seasonal forecasts for quantities of real practical value to Europe. An attempt to do this is illustrated in Fig. 10. This is another complicated-looking figure, but what it essentially depicts are:

a. a high correlation (0.75) between simulated (and inflated) and observed North Atlantic Oscillation (NAO) indices for the ensemble-mean spring forecasts (March-May) over the experimental period 1979-93; *(NB Inflation is a standard technique whereby a scaling factor is applied to match the variance of the predictions to that of*

the observed predictand, without altering the anomaly correlations between the two. In general, inflation improves a forecast.)

b. a similarly usefully high correlation (0.5) between the simulated NAO indices and the observed rainfall anomaly in Northern UK (Scotland and Northern Ireland);

c. and a smaller, but still significant, correlation (0.3) between the simulated NAO indices and the observed temperature anomaly in Southern UK (England and Wales).

Potential skill in other regions of the globe may exceed by significant amounts the skill attained over Europe and, as expected, higher and encouraging levels of skill have been reported from all the PROVOST models for the tropics and the sub-tropics. In that context, predictability is already at levels of practical value in certain areas from all the models.

(d) Tentative conclusions from the first phase of PROVOST

The early analyses of the PROVOST seasonal predictability experiments using AGCM ensembles tentatively suggest :

a. All the models have comparable magnitude of systematic errors which, in turn, are comparable with the magnitude of the observed interannual variability over the North Atlantic and Europe. In this sense, all the models perform reasonably similarly, with the UKMO Unified Model, not unexpectedly, being more different from the other three than those differ from each other.

b. Some reasonable correlations for various meteorological fields have been obtained, even over Europe. Indeed, statistically significant levels of skill have been found in the predictions for at least some fields over Europe in all seasons. However, although there is general agreement of the average levels of skill over Europe and the Northern Hemisphere, there is poor agreement between the models as to the most skilful years over Europe. Europe generally is an area of greater spread across ensembles and generally less predictability.

c. There are suggestions (at least in the UKMO model) of possible links, at least in winter, between ENSO and predictability over Europe, but these need to be confirmed.

d. There are some potentially useful spread-skill relationships; best in winter and in the tropics. However, the worst spread-skill relationships may generally be in spring and autumn, *i.e.* in the seasons of generally highest anomaly coefficient correlations.

e. For a single-season forecast, the skill using persisted SST anomalies may be generally equivalent to that with observed SST anomalies.

f. As expected, higher and encouraging levels of skill have been reported for the tropics and sub-tropics from all the models.

g. Statistical post-processing of the data may provide an option for improving skill, but tests completed to date are variable and somewhat disappointing. However, several options remain to be explored.

h. Windows of opportunity for predictions do exist in both the tropics and the extratropics which can be exploited using persisted SST anomalies and statistical post-processing of the results.

In brief, cautious optimism might be expressed over the possibility of providing forecasts with useful skill over Europe, but there is the distinct possibility that it will not be possible to produce and issue such forecasts in all seasons and in all years. Higher levels of potential skill undoubtedly exist in other regions of the globe.

(d) Next steps

The combination of the intrinsically low predictability for Europe and the relatively large systematic errors in the models means that there is bound to be overall very low skill at present for seasonal forecasts for Europe. Priorities for future work directly related to the first objective of PROVOST are therefore :

a. The need to reduce model systematic errors which are commensurate with the signal being sought.

b. The need to establish not only what skill there is but when such skill can be predicted.

c. Full and proper exploration of the skill achieved from multi-model ensembles. Such ensembles formed from two or more models are expected to provide improved skill over those formed by a single model. An initial examination of this concept, by combining ensemble members from the UKMO and ECMWF models, indicates that: the two models have significantly different climatologies; in particular, they have different low-frequency characteristics; systematic errors are reduced in the joint ensembles; and the joint-ensemble skills tend to lie close to that of the more skilful model on each occasion.

d. Additional diagnostics are needed, especially in order to examine the multi-model ensembles when all the data have been archived at ECMWF.

e. The potential of post-processing of results needs to be pursued further.

f. The study of the impact of land-surface characteristics (as opposed to SSTs) on seasonal predictability is steadily gaining prominence and uncoupled experiments are needed to examine this thoroughly.

In the context of PROVOST's other two objectives, the coupled-modelling programme is still largely at the stage of preparing the models; none of the proposed common experiments has yet been run. Nevertheless, these models have already advanced significantly during PROVOST's first year.

In the wider context, there is a need to quantify the benefits to Europe of a continuing seasonal-forecasting programme, bearing in mind that any such benefits could come from forecasts for regions beyond Europe itself and this may always be the case. There is therefore a real need to establish what constitutes useful predictive skill in the context of limited-skill seasonal forecasts. This is an aspect of the overall problem that is ripe for closer interaction between the research community currently involved in PROVOST and the potential customers for the eventual 'deliverables' from the project.

5. AN INTERNATIONAL PERSPECTIVE

(a) The CLIVAR research programme

TOGA opened the way to the future of seasonal-to-interannual climate prediction. However, questions raised during TOGA point to the need to develop more-comprehensive prediction systems and to expand the scope of climate prediction to the entire globe and to longer timescales. This challenge has been taken up by CLIVAR, A Study of Climate Variability and Predictability, now established as a major activity within the World Climate Research Programme (WCRP, 1995). In particular, the component, CLIVAR-GOALS, is designed specifically to study the seasonal-to-interannual climate variability and predictability of the Global Ocean-Atmosphere-Land System, building on the successes of the earlier TOGA programme.

(b) The CLIPS applications project

To complement the CLIVAR research programme under the WCRP, the World Climate Applications and Services Programme (WCASP), another of the four major components of the World Climate Programme, is developing the Climate Information and Prediction Services (CLIPS) project. This is designed to foster practical applications of climate information and forecasts and again seeks to build on the success of TOGA and allied research, and the resulting developing capability to predict climate on monthly, seasonal and interannual timescales.

CLIPS was endorsed by the Twelfth World Meteorological Congress in June 1995 and included in the World Meteorological Organization (WMO) Long-term Plan for 1996-2005. It is directed at one of the four major thrusts ('Climate Services for Sustainable Development') of The Climate Agenda, the overarching framework for international climate-related programmes endorsed by eight international organizations led by the WMO. The objectives of CLIPS are (WMO, 1995):

a. to provide an international framework necessary to enhance and promote climate information and prediction;

b. to facilitate the development and strengthening of a global network of regional/national climate centres, including communications and training; these

centres will act as a focus for the provision of climate information and prediction services;

c. to demonstrate the value and eventual socio-economic benefits of climate information and prediction services, and the connection of those benefits with global observing, monitoring, prediction and applications;

d. to encourage the development of operational climate predictions for periods and regions that are feasible and directed towards useful, user-oriented applications.

The CLIPS Project is at a relatively early stage of its development and an implementation plan is awaited. In the meantime, a comprehensive review of the economic and social benefits of climatological information and services has been prepared by Nicholls (1996).

(c) The International Research Institute for Seasonal-to-interannual Climate Prediction

The concept of an International Research Institute for Seasonal-to-interannual Climate Prediction (IRI-SCP) emerged around 1989 from a general consensus in the international climate research community involved in the TOGA project. Scientists realised that early results from TOGA had the potential to be useful to climate-sensitive populations, particularly those of the tropical Pacific. It was argued that such experimental forecast information could only be valuable if an institutional mechanism were in place to continually advance research and modelling related to the forecast capabilities, to disseminate forecasts on a routine basis, and to provide a centralised location for feedback on model results. In short, an IRI was needed.

In response to a request from the Intergovernmental TOGA Board, the USA, through its NOAA Office of Global Programs, has taken the lead in designing such an institute for experimental short-range climate prediction. A key initial aim was that this would employ the scientific knowledge being developed about ENSO and work with the most affected countries to learn how to use these forecasts (see, for example, Moura *et al.* (1992) and NRC (1996)). In the process, a framework for a so-called 'end-to-end' seasonal-to-interannual climate prediction programme was devised with four parallel streams of activity (see, for example, Hall (1996)):

a. regular and systematic global observations of the oceans, atmosphere and land, and associated data management;

b. research programmes to improve our understanding of processes important to climate variability and prediction, and therefore to improving our modelling capabilities;

c. integrative modelling and advance short-term climate predictions delivered regularly, and the computational infrastructure needed to implement such predictions;

d. assessment and applications programmes to further understanding of, and responses to, the effects of short-period climate variations.

It was expected that the IRI would focus mainly on the prediction and applications, whilst drawing on existing observation systems and process research programmes.

A major step towards such an institute's formal international recognition and adoption was the International Forum held in Washington, D.C. in November 1995 (NOAA 1996). This was attended by representatives of over 40 governments and 20 international organisations, in addition to individual scientists from around the world. The unanimously-supported Forum Statement, issued on 8 November 1995 (NOAA 1996), includes an agreement to the formation of an international Working Group charged with developing an action plan to address 'the design and implementation of a multi-national research capability for seasonal-to-interannual climate prediction and applications. This plan should build, to the extent possible, upon existing national, regional, and international programs. This plan would significantly contribute to furthering the Climate Agenda's commitment to an integrated program that effectively links climate research and services'. In particular, it was agreed that any such plan should be based, in part, on the IRI-SCP initiative offered by the USA.

Since the euphoria of the Forum, the US Office of Global Programs has continued with the difficult and painstaking challenge of establishing a truly multi-nationally supported and 'owned' IRI-SCP, with (to date) only limited success. The intention is that the IRI-SCP should provide an international structure that combines worldwide research capabilities, operations, and applications expertise. To this end, its most basic structure envisages a multi-national Core Facility and a wider international Network of associated institutes. The three main basic functions of the Core Facility are seen to be : research and development; experimental forecasting; and, applications and training. The scientific and institutional rationale behind the establishment of an IRI Network is that it should complement the activities at the IRI Core and vice versa. At the 'input' end, the IRI Network would consist of independent climate research and modelling groups linked to the Core. Whereas, at the 'ouput' end, the interfaces between the Core and Network would include regional application networks and research institutes, with 'operational' activities and responsibilities probably shared through the involvement of the CLIPS project, and local NMSs.

The multi-national funding of the IRI, its functions and organisational structure remain issues being actively debated by various fora promoted and stimulated by the US NOAA Office of Global Programs. In 1996, the initial IRI-SCP Core Facility was established jointly at the Lamont-Doherty Earth Observatory of Columbia University and the Scripps Institution of Oceanography, University of California. However, its establishment as a truly multi-nationally owned and run Core Facility depends on financial (and other) support coming from outside of the USA. A bottleneck in this process seems to be the articulation of an acceptable role for the Core Facility that makes a compelling case for it fulfilling a truly international requirement and thereby attracting the desired international support and funding. The international dimension of the IRI Core programme needs to add value to existing national and international activities. In this context, my personal view is that most of the emphasis in the IRI

Core Facility should be placed on the functions dealing with Applications and Training.

Training individuals in the nature and use of prediction systems and capacity building in the areas of research, climate services and forecast applications are obvious important international functions for the IRI Core, which need not be in contention with the existing activities of other national and regional institutes which are potential players in the wider IRI Network. If done effectively, with international agreement and support, such activities should not need to be duplicated unnecessarily elsewhere. This central function would provide the opportunity for developing countries to benefit specifically from research and applications training, as well as the dissemination and use of the climate forecasts themselves. Indeed, the need for adequate local training in the interpretation of seasonal forecasts is closely linked to the issue of their dissemination (discussed earlier; section 3(c)) and to the transfer of forecasting techniques and technology to regional and local forecasting centres. These activities require adequate resources to achieve success.

Pilot IRI-SCP Training Courses have already provided an indication of the usefulness of training at the Core. A considerable number of trained students have already returned to their home countries with increased understanding of climate prediction and how predictions could be applied in such areas as agriculture and water management.

Another unique strength of the Core and its activities could be in the area of forecast applications. It has already been amply demonstrated that skilful seasonal forecasts can be made for specific climatological characteristics in specific regions of the globe. The prospects are also clearly there for new methods and the extension of such forecasts to other variables and regions. Such forecasts will only be of value if they are shown to have quantified degrees of reliability and if intermediate and end users have the knowledge to interpret them, confidence in their reliability and the skills and resources to implement them. The forecasters themselves need to understand, and be understood by, both the intermediate and the end users. This will require effective communications between the various key parties along the 'end-to-end' chain from researcher to forecaster to intermediate recipient of the forecasts to the end user who applies the final, tailored product.

In a paper to the International Forum, Hunt et al (1996) pointed out that the proposed objectives of the IRI Network are complementary to the objectives of CLIPS. In particular, they should support the role of the National Meteorological and Hydrological Services in providing the best possible climate prediction services to their national communities. Both CLIVAR-GOALS and CLIPS are programmes articulated and adopted by the international agencies who have espoused The Climate Agenda. The proposed full international framework of the IRI-SCP Core Facility and Network straddles the objectives of both programmes and offers a new paradigm for organising the co-ordination and collaboration needed to actually implement these programmes. Indeed, in principle, the simultaneous developments of a proposed IRI-SCP, the CLIVAR-GOALS research programme and the CLIPS applications project bring an unparalleled opportunity to transfer new results rapidly into operational practice and into practical applications at the national and regional levels to produce

substantial benefits. Contributions from both the research community and the service community are needed for success. It remains to be seen if this opportunity will be grasped fully and to good effect.

6. CONCLUDING REMARKS

Through the use of examples from The Met. Office and elsewhere, my aims were both to inform of some of the most recent results and activities in seasonal forecasting and to raise an awareness of some of the wider issues related to the provision and use of seasonal forecasts. I hope I have at least demonstrated that the science and practice of seasonal forecasting have progressed significantly over the past decade, with the exciting prospect of much more to be achieved within the next decade, and beyond. Many of the issues are complex and go beyond the relatively simple confines of meteorology. These include :

a. How, if at all, should the dissemination of regional seasonal forecasts be organised and controlled? In particular, how, if at all, should the commercial exploitation of such potentially valuable and sensitive forecasting information be dealt with?

b. How should such forecasts be written for the recipients, both intermediate and end users? What information is needed by the intermediate (NMS) user? What is the best way of achieving customer-specific products for the end users?

c. How should we allow for the experimental nature of seasonal forecasts? Does this limit their value and should it constrain their dissemination and use?

d. How can we achieve adequate, proper training and transfer of techniques and technology to local (regional) centres?

e. How can we achieve good interaction and mutual understanding between the providers of seasonal forecasts and the users? We need to bridge the gap between what the meteorological experts believe is feasible in seasonal forecasting and the requirements and expectations of the end users.

We do not yet have clear, simple answers to many of these issues. However, as implied above, in these relatively early post-TOGA days there is much more to be done and that will be done, and there is every prospect of making scientific and political progress.

In summary, I offer a personal 'top-down' perspective :

a. We need to identify what sort of international to national hierarchy is needed; and to articulate clearly the roles of each tier and strive to make the whole system work effectively and efficiently to serve those who want and need the products.

b. The CLIPS Project Office needs to be properly funded and staffed to develop further and implement the project (led by the World Meteorological Organization).

c. Similarly, CLIVAR-GOALS needs to be implemented.

d. The US NOAA-led IRI-SCP, both the USA-based Core Facility plus the proposed worldwide network of research and 'operational' institutions, offers a mechanism for successfully implementing many of the key elements of the CLIVAR and CLIPS programmes which already have the support of the main international agencies under the umbrella of The Climate Agenda. Continued effort and thought are needed to define its role and to establish the IRI itself in the international organisational framework.

e. In Europe, the anticipated outcome from PROVOST is a capability for an operational, global, seasonal-to-interannual forecasting system. The basis is likely to be multi-model ensemble forecasts from a suite of fully-coupled atmosphere-ocean general circulation models, with an ocean data assimilation capability. Any future basic operational activity could be based at ECMWF, with the underpinning research and model development being distributed more widely throughout Europe. An 'end-to-end', co-ordinated and collaborative European programme and operational capability, which would be global but with emphasis on mid-latitudes, could make a major contribution to the IRI-SCP Network, and to CLIPS and CLIVAR.

f. The Met. Office should continue to make major contributions to the overall European effort and, where appropriate, to the IRI-SCP, CLIPS and CLIVAR. In addition, through processing, interpretation and packaging of its own, additional European and other operationally-available products, it could generate and market customer-specific products for the widest possible range of customers, including Government departments, the general public and commercial outlets.

g. I also firmly believe and recommend that all the parties concerned in such a structure should agree and adopt a common set of criteria for the recognition of 'official' long-lead forecasts. A good starting point would be the criteria for acceptability which preface the NOAA *Experimental Long-lead Forecast Bulletin* (see Section 2(c)).

Whatever is done and is achieved, I believe that the overriding aim, in a purely humanitarian context, should be to: ***reach those who stand to benefit most, with a product of potential value, which can be understood and used, and which is timely and not held up or otherwise constrained by politics, bureaucracy or commercial interests.***

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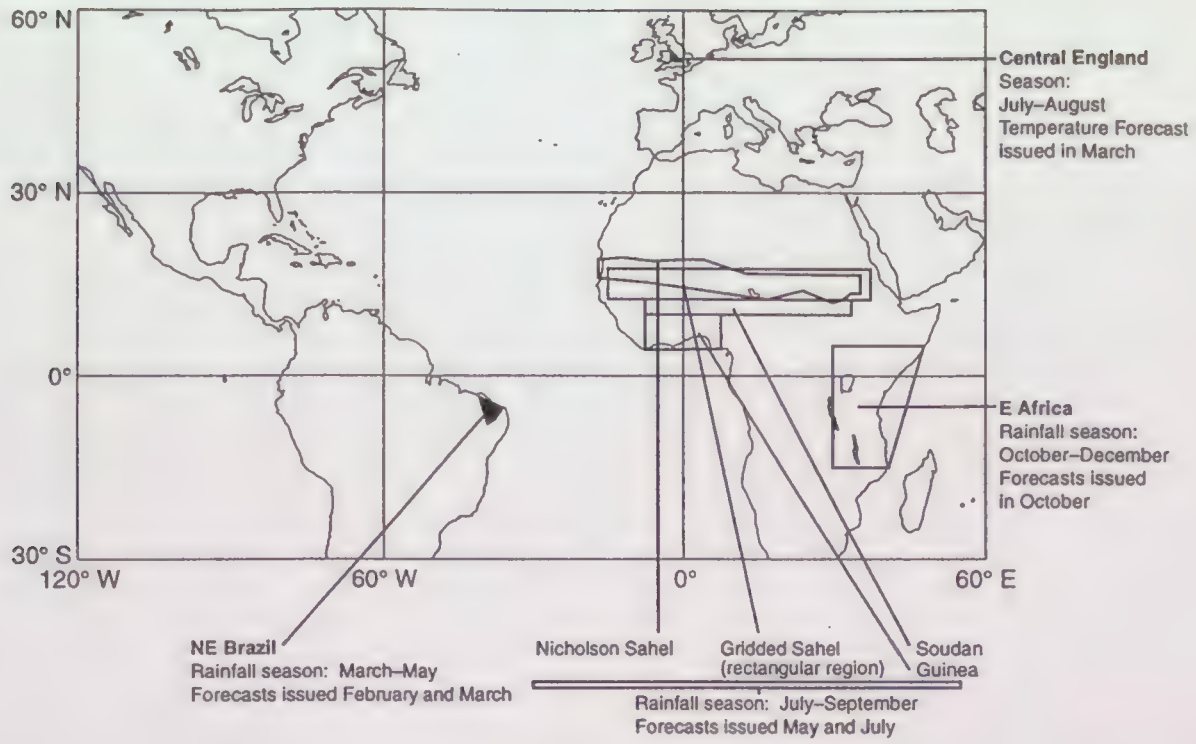

Figure 1. The regions for which quasi-operational experimental seasonal forecasts are made at present in The Met. Office.

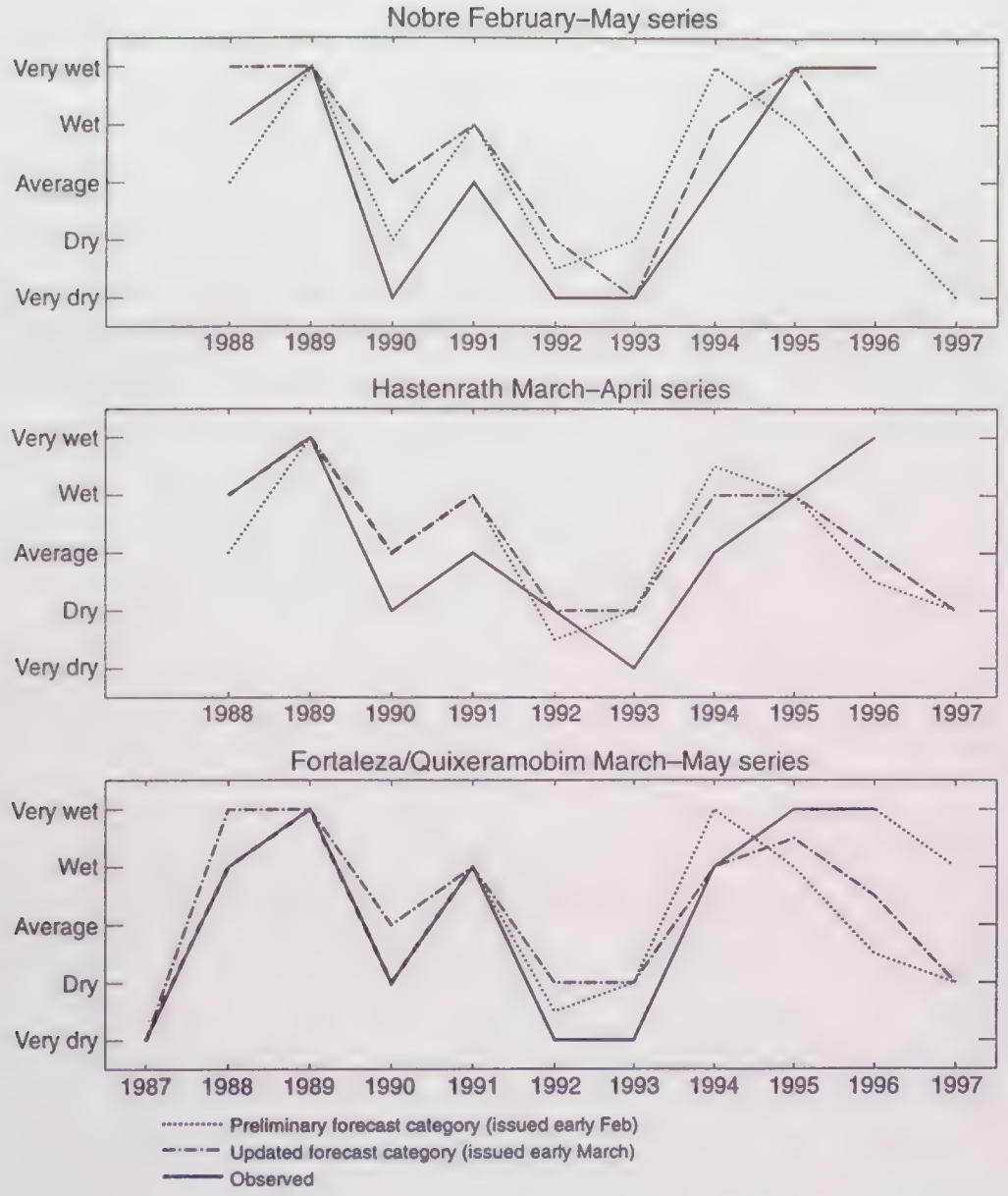

Figure 2. Verification of The Met. Office's real-time seasonal forecasts for the March-May rainfall season in North-East Brazil (see Fig 1).

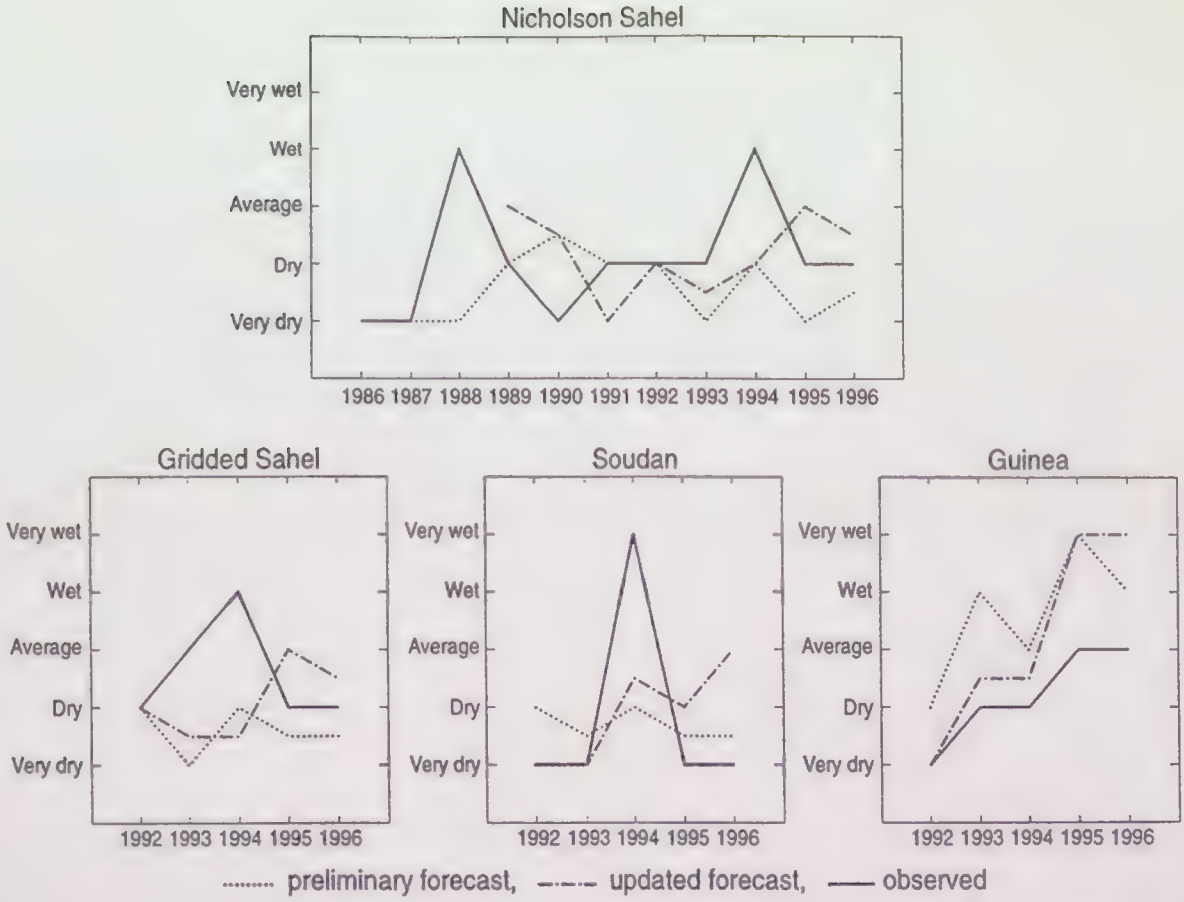

Figure 3. Verification of The Met. Office's real-time seasonal forecasts for the July-September rainfall season in parts of tropical North Africa (see Fig. 1).

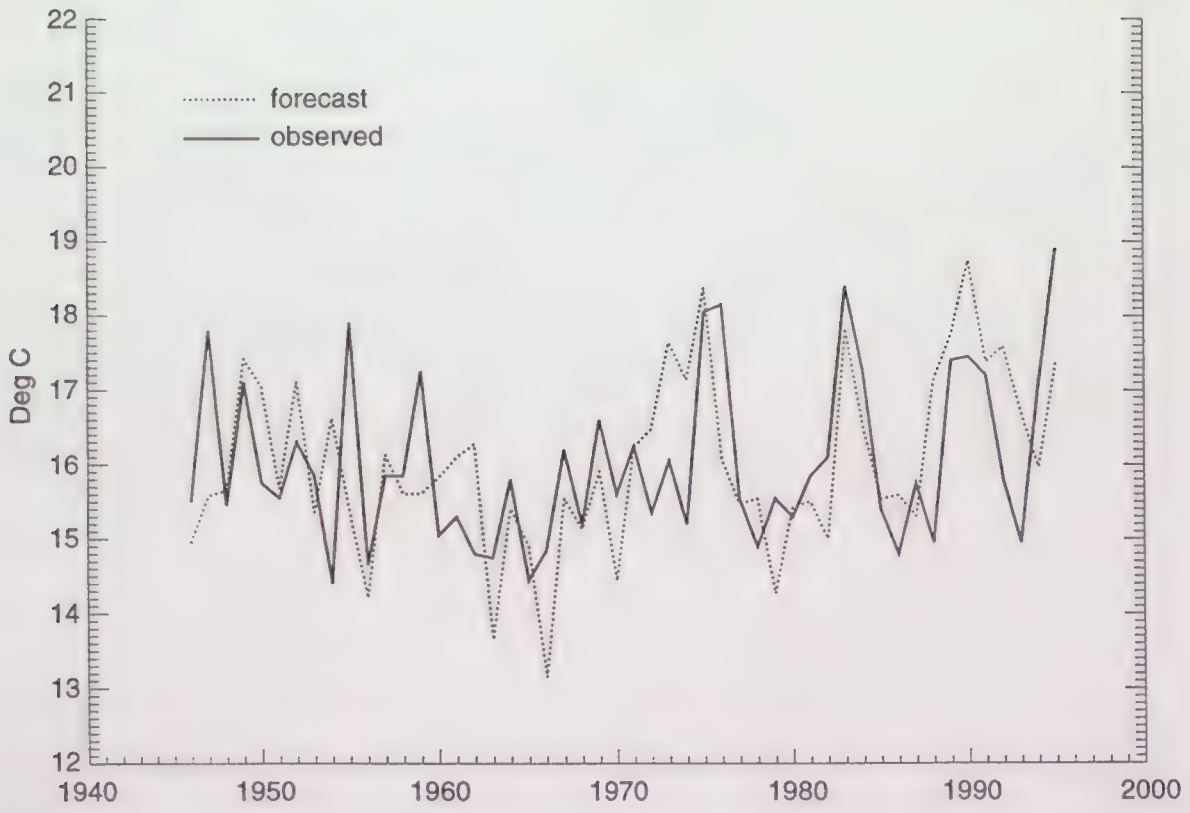

Figure 4. July-August Central England Temperature, as observed (solid line) and as forecast (dotted line) using linear regression and January-February North Atlantic sea surface temperature anomalies (Colman, 1997). The temporal anomaly correlation over the period 1946-95 is 0.49.

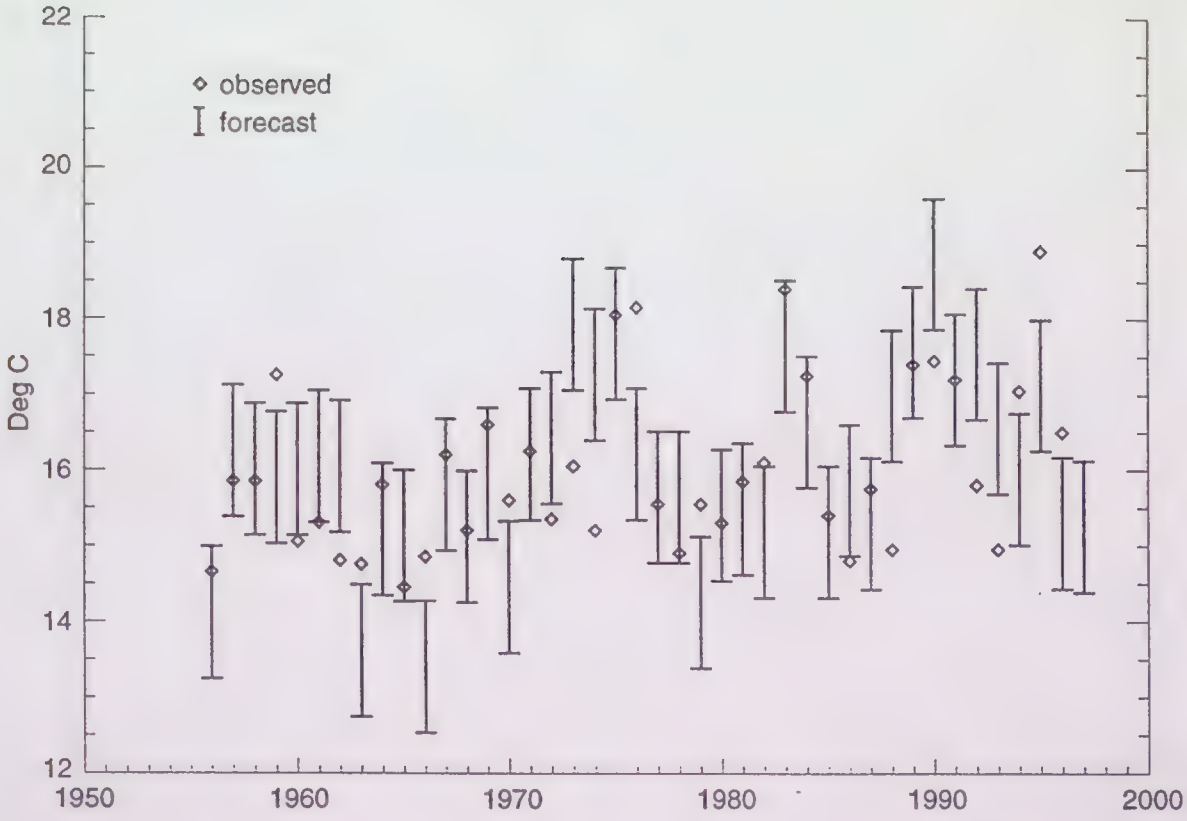

Figure 5. July-August Central England Temperature, as observed (diamonds) and as forecast (vertical bars) using linear regression and January-February North Atlantic sea surface temperature anomalies (Colman, 1997). The temporal anomaly correlation over the period 1956-96 is 0.56. The indicated forecast range is chosen such that, for this method, half the observations were within that range for 1956-96.

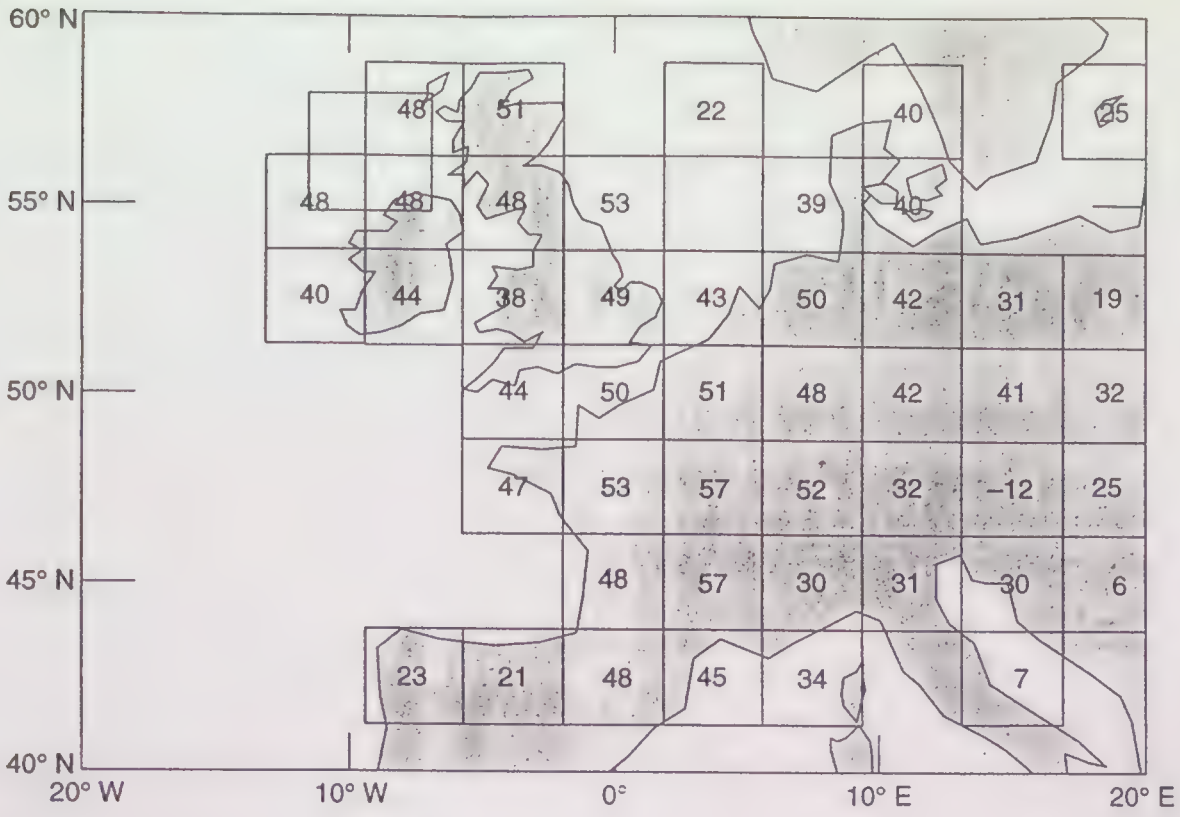

Figure 6. Correlations (times 100) of predicted (following Coleman (1997)) and observed gridded July-August land-surface temperatures over the period 1951-96 (Davey and Coleman, private communication).

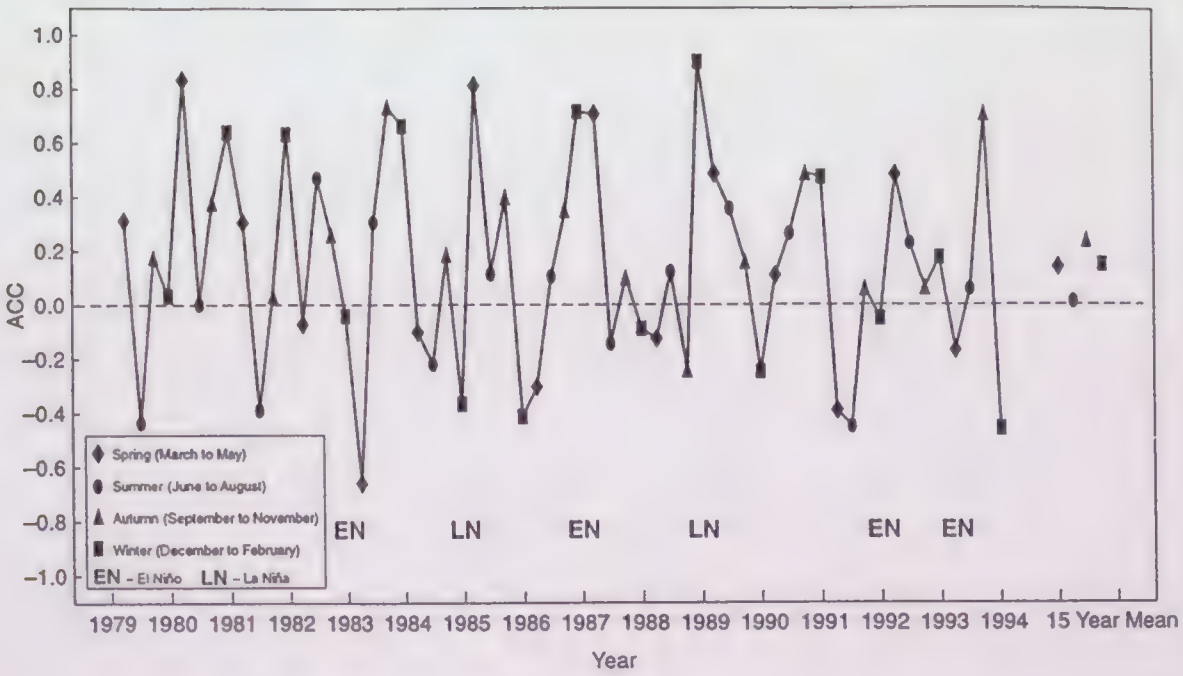

Figure 7. The anomaly correlation coefficients (ACC) between the ensemble-mean predicted 850 hPa temperature fields for Europe (75-35°N, 12.5°W-42.5°E) from the UKMO Unified Model and the corresponding, verifying ECMWF re-analysis fields for each of the 90-day main seasons throughout the period 1979-93 (Harrison *et al.*, private communication).

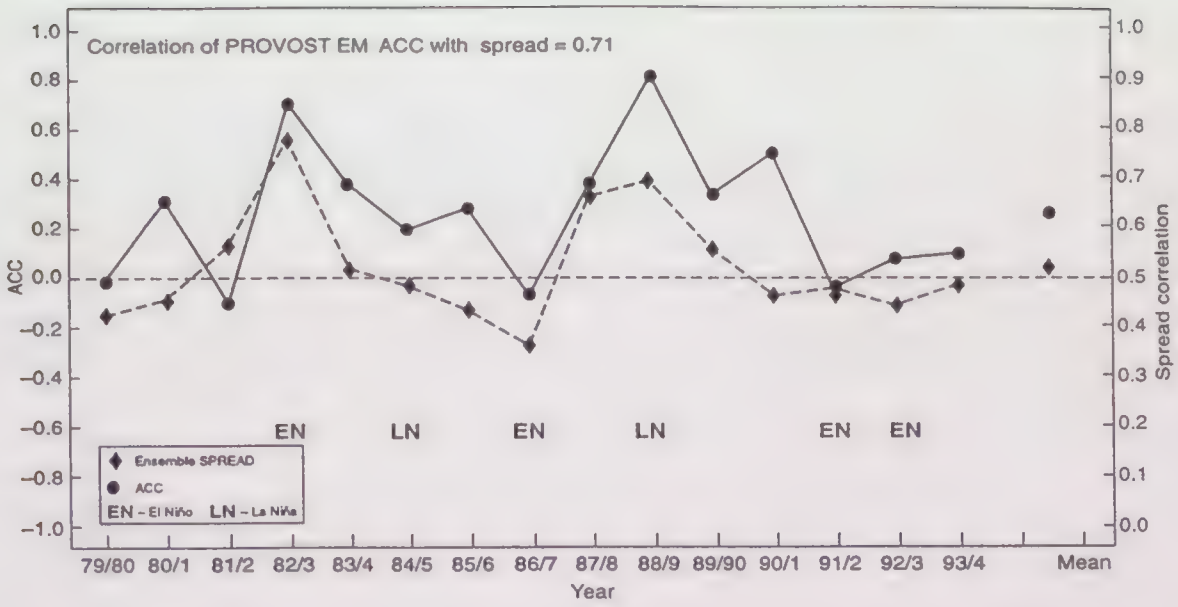

Figure 8. Anomaly correlation coefficients (ACC) between the ensemble-mean predicted 500 hPa geopotential height fields, for winter (December - February) over the Northern Hemisphere (20-80°N) from the UKMO Unified Model, and the corresponding, verifying ECMWF re-analysis fields over the period 1979-93 (solid line). Also shown (dashed line) are the spread correlations within each of the ensembles. NB High spread correlation reflects small ensemble spread. (Harrison *et al.*, private communication).

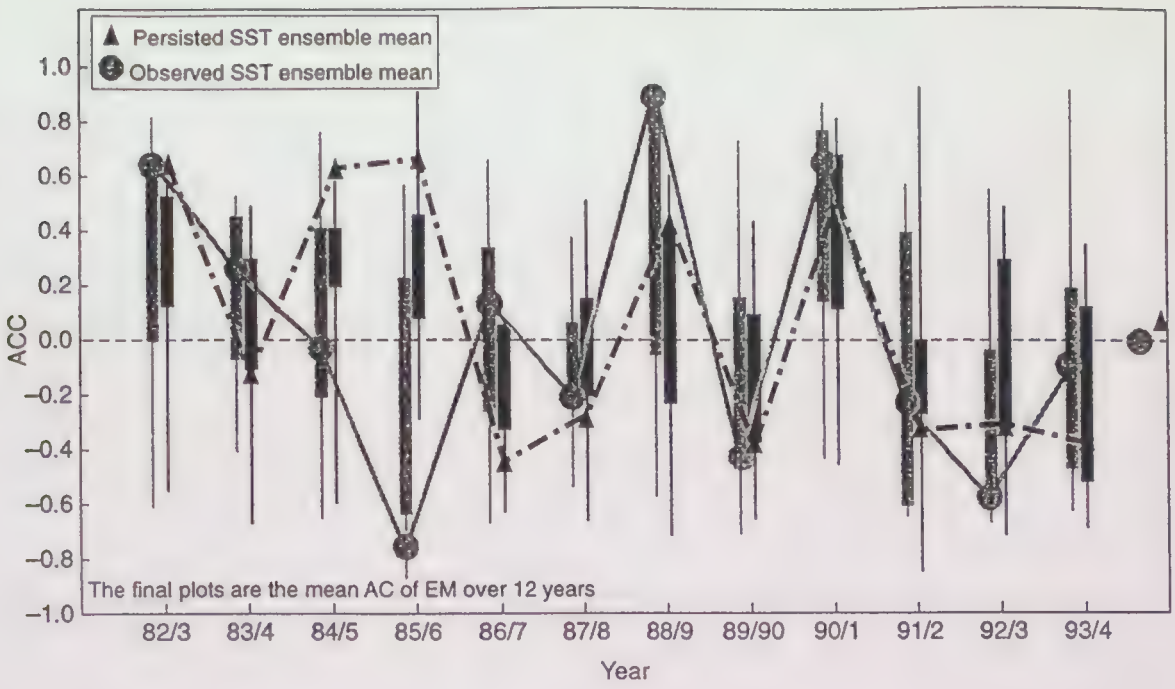

Figure 9. Winter season (December - February) anomaly correlation coefficients (ACC) between ensemble-mean predicted 500 hPa geopotential height fields over Europe (35-75°N, 12.5°W - 42.5°E) from the UKMO Unified Model, and the corresponding, verifying ECMWF re-analysis fields over the period 1982-93. The circles, joined by solid lines, depict ACCs obtained with surface forcing by observed sea-surface temperatures. The triangles, joined by broken lines, depict ACCs obtained with surface forcing by persisted sea-surface temperatures. The ensemble quartiles and ranges are also shown (vertical bars). (Harrison *et el.*, private communication).

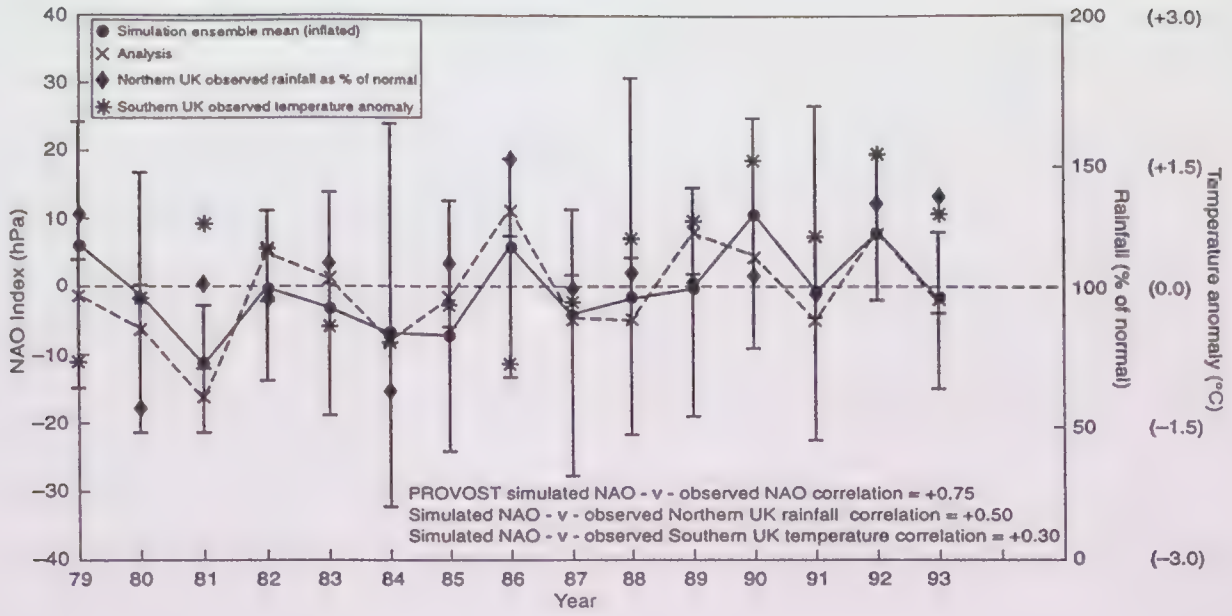

Figure 10. North Atlantic Oscillation (NAO) indices (hPa) constructed from the pressure difference between the Azores and Iceland for March-May over the period 1979-1993, from simulations (inflated) with the UKMO Unified Model (circles joined by solid lines) and the corresponding, verifying ECMWF re-analysis fields (crosses, joined by dashed lines). Vertical bars indicate the range of (inflated) values in an ensemble. Also plotted are observed rainfall anomalies (diamonds; percentage of normal) for northern UK regions (*i.e.* Scotland and Northern Ireland), and observed temperature anomalies (stars; °C) for southern UK regions (*i.e.* England and Wales). (Harrison *et al.*, private communication).

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